ICRC 2001

Observations of Mkn 421 using Pachmarhi Array of Čerenkov Telescopes

P. N. Bhat, B. S. Acharya, V. R. Chitnis, P. Majumdar, M. A. Rahman, B. B. Singh and P. R. Vishwanath

Tata Institute of Fundamental Research, Colaba, Mumbai, 400005, India

Abstract. Pachmarhi Array of Čerenkov Telescopes (PACT), based on wavefront sampling technique, has been used for detecting TeV gamma rays from galactic and extra-galactic γ-ray sources. The Blazar, Mkn 421 was one such extra-galactic source observed during the winter nights of 2000 and 2001. We have carried out a preliminary analysis of the data taken during the nights of January, 2000 and 2001. Results show a significant gamma ray signal from this source during both these periods above a threshold energy of 900 GeV. The source was contemporaneously observed by CAT imaging telescope during the first episode of January 2000 while HEGRA CT1 was observing the source during the second episode. Both these observations have detected variable γ-ray emission this source and they reported that it was flaring during both these periods. The light curve in the TeV gamma ray range derived from the first PACT observations during both these episodes is in agreement with that reported by other experiments. The analysis procedure and the preliminary results will be presented and discussed.

1 Introduction

Mkn 421 is an X-ray selected closest (z=0.03) BL Lacertae object exhibiting extreme variability in VHE $\gamma-$ray emission. This is the first extra-galactic object discovered at TeV energies [Punch *et al.* (1992)]. Variability time scale as low as 15 minutes observed from this source [Gaidos *et al.* (1996)] implies a compact emission region of dimension R less than 10^{-4} pc which is only an order of magnitude larger than the radius of the event horizon of a 10^8 solar mass black hole. Correlations observed between X-rays and TeV $\gamma-$rays [Macomb *et al.* (1995); Buckley *et al.* (1996); Catanese *et al.* (1997) are most easily explained as emissions at both wavelengths produced by the same population of high energy electrons. However models which produce $\gamma-$rays primarily through proton interactions [Mannheim (1993)] can

Correspondence to: pnbhat@tifr.res.in

also explain the observations so far. More observations are still needed to understand the nature of the proginitors of TeV $\gamma-$rays.

2 Observations

PACT is situated in the central Indian hill station Pachmarhi (longitude: $78° 26'$ E, latitude: $22° 28'N$ and altitude: 1075 m). It consists of an array of Čerenkov detectors, each of area $4.35\ m^2$, deployed in the form of a rectangular array. The detectors in the E-W direction have a separation of $25\ m$ and in the N-S direction separation is $20\ m$. Each telescope consists of 7 parabolic reflectors mounted para-axially on a single equatorial mount [Bhat (1998, 2001)].

The array has been divided into 4 sectors of six telescopes each and each sector has its own data acquisition system which are networked with the master data acquisition system. The analog signals from the seven individual mirrors of a telescope are added in phase to generate a 'royal sum'. The trigger is generated when any 4 out of 6 royal sums are present in any sector. Following an event trigger the TDC and the ADC informations from peripheral mirrors of each telescopes, the UTC from a real time clock and the latch information are recorded. The master recording system at the main control room records the TDC information from all royal sums [Upadhya *et al.* (2001)].

PACT has become completely operational since December 2000. Two of the four sectors (consisting of a total of 12 telescopes) were ready about an year ago when the science observations were started. Various celestial point sources of TeV γ-rays have been observed. Among these are the galactic sources like the Crab Nebula, Geminga and extra-galactic sources like Mkn 421 and Mkn 501. We have detected positive signal from the Crab Nebula [Bhat (2001)] and the detected flux is consistent with the expected sensitivity of PACT.

The flaring Blazar Mkn 421 has been observed by PACT (using sectors 3 & 4 only during January 2000 flare and all

the 4 sectors during the January 2001 flare). We have a total of 73.3 hrs of ON-source date and 50.6 hrs of OFF-source data during the 2000 observing season while we have logged 45.6 hrs of ON-source data and 39.7 hrs of OFF-source data until the end of February during 2001 observing season.

3 Analysis

From the vast amount of data we have carried out only a preliminary analysis of the January 2000 and 2001 data because of the flaring activity reported by other groups [Gouiffes & Degrange (2000); Boerst & Remillard (2001)]

The arrival direction of each event with more than 8 telescopes participating, has been estimated using a plane front approximation. In this preliminary analysis only the telescope TDC values are used. The TDC information from individual mirrors in a telescope are not used. The mean value of the χ^2 values of the plane front fit to the TDC data is around 1. We rejected events with χ^2 values more than 1 standard deviation above the mean. The off-source data covering the same hour angle range as the corresponding on-source run is taken on the same night as the source run or the following night. On & off -source data segments are of same duration. The space angle between the direction of the primary estimated as mentioned above and the source or the off-source direction as the case may be is estimated for each accepted event. The space angle distributions are generated both for on & off source data. The two distributions are normalized from the number of counts in the space angle range $3° − 5°$ and the off-source distribution is subtracted from the on-source distribution to estimate the γ-ray signal from the source. Different space angular ranges were used for normalization and the RMS value of the estimated signal is used as a measure of systematic error on the signal. It has been found that the signal strength is not a sensitive function of space angle range used for normalization. In all cases the space angle distributions of the signal are similar, showing excess close to zero and reaching zero counts with increasing space

angle while the FWHM of this distribution is consistent with the angular resolution [Majumdar *et al.* (2001)].

4 Results

Figure 1 shows a plot of the γ-ray count rate from Mkn 421 during each night of observation on January 11, 12 & 13, 2000 as a function of epoch. These are shown as open squares and the error bars include systematic errors as mentioned above. Also shown in the same figure are the counting rates above 250 GeV from the CAT imaging telescope (shown as asterisks, Gouiffes & Degrange (2000)). These rates are multiplied by a factor of 10 and re-plotted (shown as diamonds) for better comparison of the variability of the two independent results. It can be seen that the two light curves, one with primary γ-ray > 250 GeV [Piron *et al.* (1999)] and the other with primary γ-ray > 900 GeV are very similar.
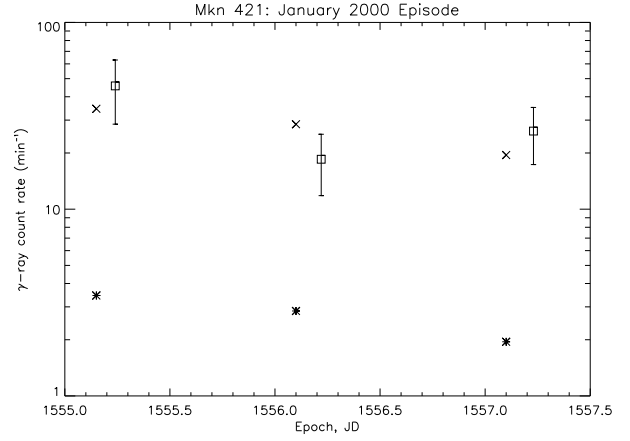

Fig. 1. The γ-ray count rate from Mkn 421 as a function of epoch (MJD) during January 2000. The count rate observed by CAT during January 2000 are shown as asterisks. These are re-plotted after multiplying by 10 (shown as crosses) for comparison of the variability in the two independent observations.

Similarly, Figure 2 shows the nightly rates of TeV γ-rays from Mkn 421 above 900 GeV from PACT observations during January 2001. Also shown in the same plot are the γ-ray (> 500 GeV) count rate contemporaneously detected by HEGRA CT1 [Boerst & Remillard (2001)]. Figure 1 also shows a re-plot of the HEGRA CT1 rates multiplied by 5 as diamonds to enable one to compare the counting rate variability in the two independent observations. During both the episodes there is a good agreement between the two light curves despite different energy thresholds.

5 Discussions

It may be noted that this is only a preliminary result and hence we have not estimated the TeV γ-ray flux from this source during the flaring activity. The enhanced counting rate from PACT as compared that from imaging telescopes, is attributed to its increased collection area.

We have carried several checks to improve the confidence level of the signal seen by PACT. A positive signal could result, for example, if the space angle distribution of background region has some systematic problem. Hence we compared the background data taken during two different nights and after subtracting one from the other no positive excess was detected in any space angle range. In addition, we compared an ON-source data with several nights' background data separately and estimated the signal in each case. Table 1 shows the systematic variation in the signal strength resulting from the systematic variation in the background data taken during different nights. In addition, each on/off source data set has been subdivided as per the number of telescopes that have participated during the event. Each subset was independently analyzed and the signals estimated. The variation of signal strengths from segment to segment were consistent
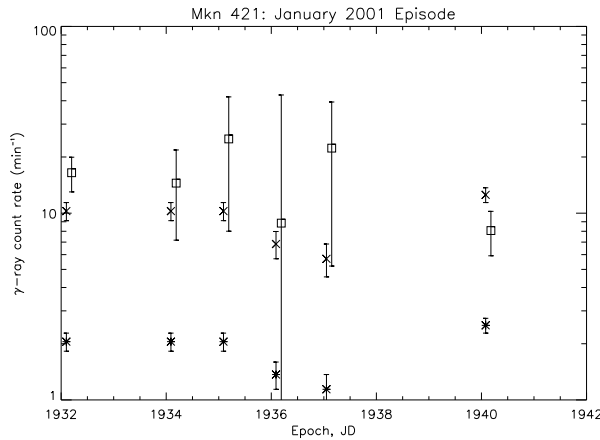
Fig. 2. The γ-ray count rate from Mkn 421 as a function of epoch (MJD) January 2001. The count rate observed by observed HEGRA CT1 during January 2001 are shown as asterisks. These are re-plotted after multiplying by 5 (shown as crosses) for comparison of the variability in the two independent observations.
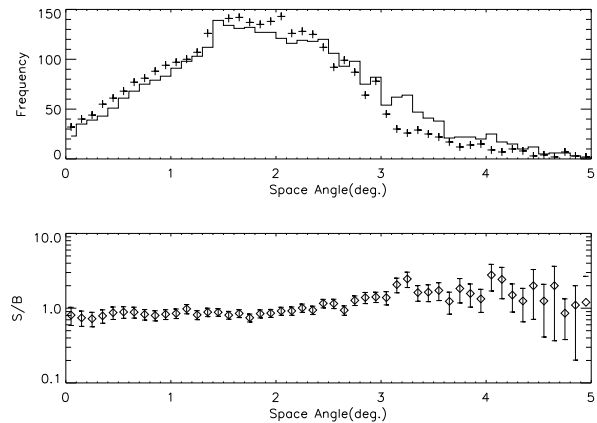

Fig. 3. The space angle distribution of two sets of background data taken on two different nights. The two data sets span the same hour angle range (upper panel). The lower panel shows the ratio of the two distributions as a function of space angle showing that when two background data-sets are compared no signal is seen adding credibility to the signal from the source reported here.

within the expected variation in each run.

Figure 3 shows the the space angle distribution of events when two sets of background data are compared. The space angle distribution of the ratio's show no evidence of any signal showing that the systematic variations, if any, in the background data cannot masquerade as a γ-ray signal.

6 Conclusions

A variable TeV γ-ray signal above 900 GeV has been detected by PACT for the first time during both the episodes in January 200 and January 2001. The variability measurements are compatible with those independently seen by other atmospheric Čerenkov telescopes. The fourth run taken in January 2000 did not show any signal once again confirming that PACT analysis is working. However there are more data from this source to be analyzed.

Table 1. A table showing the consistency of signal strength with different backgrounds

# of ON Source events	# of OFF Source events	Excess (S-B)	Sigma $\frac{(S-B)}{\sqrt{S+2B}}$	Durn (mins.)	γ-ray rate (min^{-1})
14543	11508	3035	15.7	136.6	22.2±4.7
3311	2104	1207	16.4	68.9	17.5±4.2
7180	5771	1409	12.4	68.4	20.6±4.5
6604	4654	1950	15.5	62.2	31.4±5.6

References

Bhat, P. N., 1998, *"High Energy Astronomy & Astrophysics"* , Proc. of the Int. Colloquium to commemorate the Golden Jubilee year of Tata Institute of Fundamental Research, Ed: P. C. Agrawal and P. R. Vishwanath, University Press, 370

Bhat, P. N., 2001, *Wavefront Sampling Technique: VHE $\gamma-ray$ Experiments in India*, ibid.

Boerst, H. G. and Remillard, R. (for HEGRA Collaboration), 2001, IAU Circular No. 7568 and http://www-hegra.desy.de/mrk-421/

Buckley, J. H., *et al.*, 1996, *Astrophys. J*, 472, L319.

Catanese, M., 1997, *et al.*, 1997, *ApJ*, 487, L143.

Gaidos, J. A. *et al.*, 1996, *Nature*, 383, 319.

Gouiffes, C. and Degrange, B. (for CAT Collaboration), 2000, IAU Circular No. 7345.

Macomb, D. J., *et al.*, 1995, *Astrophys. J*, 449, L99.

Mannheim, K., 1993, it Astron. & Astrophys., 269, 67

Majumdar, P. *et al.*, 2001, *Angular Resolution of the Pachmarhi Array of Čerenkov Telescopes*,*Wavefront Sampling Technique: VHE $\gamma-ray$ Experiments in India*, ibid.

Piron, F. for the CAT Collaboration, 1999, *26th International Cosmic Ray Conference, Utah*, OG 2.1.09; Astro-ph/9906102.

Punch, M. *et al.*, 1992, *Nature*, 358, 477.

Upadhya, S. S. *et al.*, 2001, *Distributed Data Acquisition System for Pachmarhi Array of Čerenkov Telescopes*, *Wavefront Sampling Technique: VHE $\gamma-ray$ Experiments in India*, Proc. of *Int. Symp. on Gamma-ray Astrophysics through Multiwavelength Expts*: GAME-2001, March 8-10, 2001, Mt. Abu, India (Ed. R. K. Kaul and C. L. Kaul)